CHAPTER 11

THE STRUCTURE OF MATTER

n this chapter, you will learn about atoms, and how they combine to form ions and molecules.

ATOMS AND SUBATOMIC PARTICLES

MAJOR IDEAS

A. All matter is made up of minute particles known as atoms. Atoms are composed of protons, neutrons, and electrons.

B. Different isotopes of the same element have different numbers of neutrons.

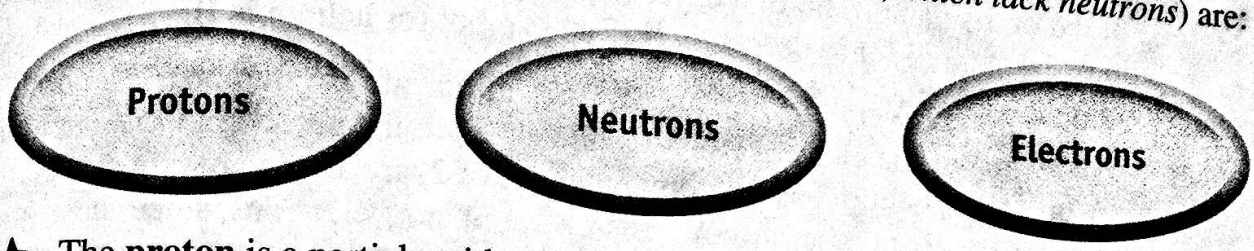
C. Atoms react with other atoms to obtain a complete outer energy level. Atoms ***transfer*** electrons to form ionic bonds. Atoms share electrons to form covalent bonds, which hold together molecules.

D. Both ***before*** and ***after*** a chemical reaction, the number of atoms and total mass is the same.

Anything that has **mass** and occupies space is known as **matter**. Air, glass and water are matter. Light and electricity, however, are not matter. All matter is made up of minute particles alled atoms. An **atom** is the smallest part of an element that has the physical and chemical roperties of that element. An **element** is a substance with only one kind of atom. For example, ll aluminum is made up of aluminum atoms.

THE PARTS OF THE ATOM

Scientists once thought that atoms were indivisible. However, in the 20th century, scientists discovered that atoms are made up of even smaller **subatomic** particles. The three most important subatomic particles found in all atoms (*except hydrogen atoms, which lack neutrons*) are:

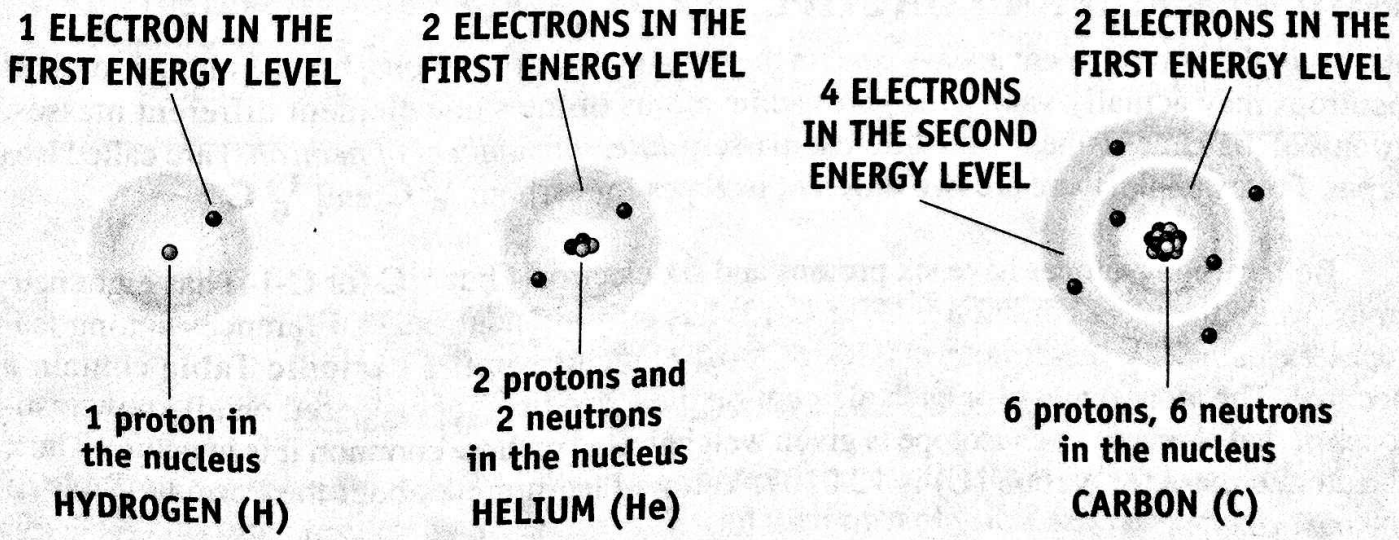


★ The **proton** is a particle with a positive charge and a mass of 1.673×10^{-24} grams, or **1 atomic mass unit**. Protons are located in the **nucleus** of the atom. The nucleus is at the dense center of the atom.

★ The **neutron** is a neutral particle with approximately the same mass as the proton (*1 atomic mass unit*). Neutrons are also located in the nucleus.

★ **Electrons** are small, negatively charged particles that move around the nucleus at very high speeds. Compared to protons and neutrons, they have no significant mass. They are attracted to the positively charged protons in the nucleus. No one can actually measure the speed, direction, and location of an electron. However, scientists believe electrons occupy different **energy levels** or **shells**, based on the way atoms behave. The first energy level can hold up to two electrons. The second energy level can hold up to eight electrons. You will learn more about these energy levels, or shells, later in this chapter.

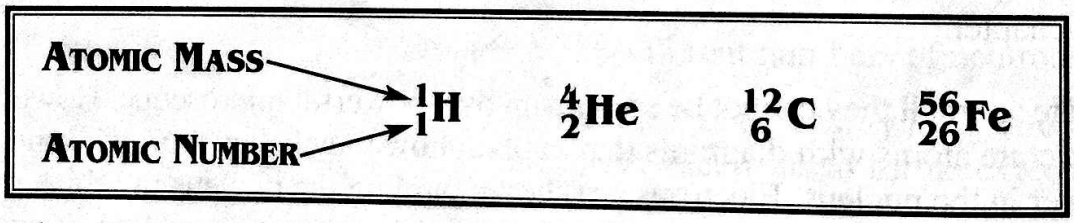
Atoms are so small they cannot be seen, even by a powerful microscope. However, scientists often try to picture atoms with diagrams that explain how they behave: protons and neutrons are shown together in the nucleus. Electrons are shown circling the nucleus in orbits, or more accurately, as **electron clouds**. The following illustrations help us understand how atoms act. In reality, the electrons are actually much smaller and farther from the nucleus than shown here.



- **Electrically Neutral.** Atoms have the same number of positively charged protons and negatively charged electrons. They therefore have no electrical charge and are considered neutral.
- **Atomic Symbols.** To identify each element, scientists use a symbol of one or two letters, based on its name. The first letter is always capitalized, but not the second. For example, the symbol for hydrogen is **H**. The symbol for helium is **He.**
- **Atomic Numbers.** Every element has its own unique atomic number. The number of protons an atom of the element has determines its atomic number. In the example on the previous page, helium has an atomic number of 2, and carbon has an atomic number of 6. The atomic number also reveals the number of electrons, since these are the same as the number of protons.
- **Atomic Mass.** To determine the mass of an atom, add the number of its protons and neutrons. The mass of a typical hydrogen atom is 1, of a typical helium atom is 4, and of a typical carbon atom is 12. If you know the atomic mass and the atomic number of an atom, you can determine the number of its protons, neutrons, and electrons.

ATOMIC NUMBER = NUMBER OF PROTONS = NUMBER OF ELECTRONS
ATOMIC MASS – ATOMIC NUMBER = NUMBER OF NEUTONS

Scientists often write the atomic mass of the element on the upper left of the symbol, and the atomic number on the lower left.



ISOTOPES AND RADIOACTIVE DECAY

Atoms of the same element always contain the same number of protons, but the number of their neutrons may actually vary. This gives some atoms of the same element different masses. Atoms of the same element with different masses (*different numbers of neutrons*) are called **isotopes.** For example, there are two different isotopes for carbon: $^{12}_{6}C$ and $^{14}_{6}C$

Both carbon isotopes have six protons and six electrons, but ^{14}C (or C-14) has eight neutrons, while the more common ^{12}C (or C-12) has only six neutrons. Differences among isotopes explain why the atomic masses of most elements on the **Periodic Table** contain a decimal. The atomic mass for each element on the Periodic Table is based on all known isotopes of that element. Each isotope is given weight based on how common it is in nature. Thus, the atomic mass for carbon (C) is 12.0107. You will learn more about the Periodic Table in the next chapter.

Radioactivity. The atoms of some elements have nuclei that are unstable. The force holding the nucleus together isn't strong enough to overcome the electrical force pushing the protons apart. The nuclei of these atoms break apart in a process of spontaneous decay known as **radioactivity**. Sometimes different isotopes of the same element are either stable or radioactive. Radioactive substances undergo nuclear decay by emitting both particles (*such as protons*) and high-energy, wavelike radiation. When a radioactive substance decays, a new element is often formed. This processes is known as **transmutation**. The decay of radioactive substances takes place at fixed and predictable rates. The time in which it takes half of a radioactive substance to decay is known as its **half-life**.

APPLYING WHAT YOU HAVE LEARNED

- An atom of nickel has an atomic number of 28 and an atomic mass of 59. How many protons, neutrons, and electrons does it have?
- What are the differences between these two atoms? $^{35}_{17}Cl$ and $^{37}_{17}Cl$

WHAT YOU SHOULD KNOW

A. All matter is made up of minute particles known as atoms. Atoms are made up of even smaller **subatomic** particles known as protons, neutrons, and electrons.

B. **Protons** are located in the dense nucleus of the atom. The proton is a particle with a positive charge. **Neutrons**, also located in the nucleus, are neutral. **Electrons** are small, negatively charged particles that move around the nucleus at high speeds.

C. Atoms have the same number of positively charged protons and negatively charged electrons. To identify each element, scientists use a symbol of one or two letters.

D. Atoms of the same element with different masses (*different numbers of neutrons*) are called **isotopes**.

E. The atoms of some elements have nuclei that are unstable. The nuclei of these atoms break apart in a process of spontaneous decay known as **radioactivity**. The time in which it takes half of a radioactive substance to decay is known as its **half-life**.

IONS AND MOLECULES

Atoms react with each other to form ions and molecules. Electrons play a key role in this process. This often results in new substances with their own physical and chemical properties.

CHEMICAL REACTIONS

In a chemical reaction, two or more substances combine to form new substances with different properties. The number and types of atoms and the total mass remain the same ***before*** and ***after*** the reaction. For example, when a magnesium atom forms ionic bonds with two chlorine atoms, the reaction is: $Mg + 2Cl \rightarrow MgCl_2$. There are two chlorine atoms and one magnesium atom both before and after the reaction.

When two hydrogen molecules, ($2H_2$) form covalent bonds with one oxygen molecule, (O_2), the chemical reaction is:

$$2H_2 + O_2 \rightarrow 2H_2O$$

If you examine this equation, the number of atoms at the beginning of the reaction is again the same as the number of atoms at its completion. On both sides of the equation, there are the same six atoms: four hydrogen atoms and two oxygen atoms. However, they are combined differently. On the left of the equation, they form three gas molecules. On the right side, the atoms have combined into two water molecules. The gases on the right side of the equation are both **elements**: the molecules are made up of the same kinds of atoms. Water is a **compound**: it has different kinds of atoms combined together. Although water has both hydrogen and oxygen atoms, it is a completely different substance with its own chemical and physical properties.

UNDERSTANDING BALANCED CHEMICAL EQUATIONS

$$2H_2 + O_2 \rightarrow 2H_2O$$

When scientists write chemical formulas and equations, they follow certain rules:

- ★ The ***reactants*** are usually written on the left side of the reaction. The arrow indicates the direction of the reaction. Here, oxygen and hydrogen combine to form water. The ***products*** are written on the right side after the arrow.
- ★ To indicate the number of **atoms** in each molecule, they put a number below the line after the atomic symbol. In H_2, the small number $_2$ indicates that the hydrogen molecule has two atoms. If there is no number after the atomic symbol, then the number is assumed to be one. In the water molecule H_20, there is only one oxygen atom.
- ★ To indicate the number of **molecules** involved in the reaction, scientists write the number in front of the molecule. In this example, "$2H_2$" indicates that there are two hydrogen molecules. When there is no number in front of a molecule, the number of molecules is one. In ($2H_2 + O_2 \rightarrow 2H_2O$), there is only one oxygen molecule on the left side of the equation.
- ★ The equation is **balanced** if there are the same number of atoms on each side of the equation. Multiply the number of molecules by the number of atoms of each type to check. Here there are four hydrogen and two oxygen atoms on each side, so the equation is balanced.

THE CONSERVATION OF MASS AND ENERGY

The total mass of the reactants before a chemical reaction and the mass of the products after t reaction must always be the same. This illustrates the principle known as the **conservation mass**. Mass cannot be created or destroyed in a chemical reaction or by other ordinary mea

A chemical reaction will also either require or produce energy. This energy is stored released by the ionic or covalent bonds. If energy is released, it will usually be spread to the s roundings in the form of heat. This energy does not go away, it just spreads to neighboring m ter. If energy is required, it must be supplied by some outside source. Energy, like matter, a cannot be created or destroyed, although it can be stored in chemical bonds. This principl known as the **conservation of energy**.

APPLYING WHAT YOU HAVE LEARNED

- How does an ionic bond differ from a covalent bond?
- Explain the principle of conservation of mass.
- Methane (CH_4) is combined with oxygen (O_2) to produce carbon dioxide (CO_2) and water (H_2O). Write a balanced chemical equation representing this reaction.

WHAT YOU SHOULD KNOW

- ★ Opposite electrical charges attract and similar charges repel each other. The attraction between the positively charged nucleus and negatively charged electrons holds an atom together.
- ★ Electrons can only exist in particular **energy levels** around the nucleus. Each energy level can hold only a specific number of electrons.
- ★ The electrons in the outermost energy level of an atom are known as its **valence electrons**. An atom is always most stable when it has filled its outermost energy level.
- ★ Some atoms complete their outermost energy levels by transferring electrons and becoming ions. An **ionic bond** forms between the positively and negatively charged ions. Some atoms complete their outermost energy level by *sharing* electrons. The same pair of electrons move around the nuclei of both atoms, forming a **covalent bond**.
- ★ In a chemical reaction, two or more substances combine to change their chemical properties. The number and type of atoms and the total mass must be the same b***efore*** and ***after*** the reaction. This demonstrates the conservation of mass.

CHAPTER STUDY CARDS

Atoms and Subatomic Particles

Atom. Smallest unit of matter unique to a particular element. Atoms contain:

- ★ **Protons.** Positively charged; all atoms have protons; have atomic mass; located in the nucleus of the atom.
- ★ **Neutrons.** Neutral in charge; the same mass as the proton; also located in the nucleus of the atom.
- ★ **Electrons.** Negatively charged; attracted to nucleus' positive charge; move around the nucleus at high speeds in different energy levels; same number as protons.

Atomic Notation

- ★ **Atomic Symbol.** Scientists use a symbol of one or two letters to identify elements.
- ★ **Atomic Number** = number of protons.
- ★ **Atomic Mass** = the number of protons and neutrons.

Radiation

- ★ **Isotopes.** Atoms of the same element with different numbers of neutrons.
- ★ **Radioactive Decay.** Some elements or isotopes of elements have unstable nuclei, which break apart, causing radioactivity.

Ions and Molecules

- ★ **Energy Levels.** Electrons can only exist in particular **energy levels** around the nucleus. Each level can hold only a specific number of electrons. An atom is most stable when it fills its outermost energy level
- ★ **Ionic Bonds.** When a transfer of electrons occurs between two or more atoms, negatively charged ions are attracted to positively charged ions.
- ★ **Covalent Bonds.** Some atoms (nonmetals) complete their outer levels by sharing electrons. The same pair of electrons move around the nuclei of both atoms in covalent bonding.

Chemical Reactions

- ★ **Chemical Reactions.** These are combinations of substances that result in one or more new substances with new physical and chemical properties.
- ★ **Balancing Equations.** There should be the same number of atoms on each side of the equation. Multiply the atoms in each molecule by the number of molecules to see that they balance: $2H_2 + O_2 \rightarrow 2\ H_2O$
- ★ **Conservation of Mass.** Matter cannot be created or destroyed in a chemical reaction.

CHECKING YOUR UNDERSTANDING

1 Which statement correctly describes protons and neutrons?

A. They have the same mass and the same electrical charge.
B. They have the same mass but different electrical charges.
C. They have different masses but the same electrical charge.
D. They have different masses and different electrical charges.

PS:A 9–1

This question tests your understanding of subatomic particles. Both protons and neutrons are located in the nucleus. Each proton has an atomic mass of one and a *positive* electrical charge. Each neutron has an atomic mass unit of one and *no electrical charge*. Only choice B is correct in stating that they both have the same masses but different electrical charges.

Now try answering some additional questions about the structure and properties of atoms and subatomic particles.

Use the table that follows to answer questions 2 through 4:

DATA TABLE

Substance	Number of Protons	Number of Electrons
Sulphur	16	18
Chromium	24	24
Cobalt	27	24
Americium	95	92

2 Which of these substances is electrically neutral?

A. sulphur
B. chromium
C. cobalt
D. americium

- Examine the Question
- Recall What You Know
- Apply What You Know

PS: A 9–2

3 Which statement is true about the electrical charges assigned to the electrons and protons of the elements in the table?

A. The electrons and protons are both positive.
B. The electrons are positive and the protons are negative.
C. The electrons are negative and the protons are positive.
D. The electrons and protons are both negative.

PS: A 9–2

4 Which of the substances on the table is a negatively charged ion?

A. sulphur
B. chromium
C. cobalt
D. americium

PS: B 9–5

5 Which spontaneously emits radiation and particles from the nuclei of its atoms?

A. inert gases
B. radioactive isotopes
C. chemical reactions
D. covalent bonds

6 Which force holds atoms together?

- ♦ Examine the Question
- ♦ Recall What You Know
- ♦ Apply What You Know

PS: A 9–6

A. attractive electrical forces between protons and electrons
B. magnetic forces of attraction
C. frictional forces between protons and electrons
D. gravitational force

7 The composition of the nucleus of carbon varies from one isotope to another. The symbol for one isotope of carbon is $^{14}_{6}C$. How many neutrons are contained in this isotope?

A. 6
B. 8
C. 14
D. 20

PS: A 9–1

Use the chart below to answer the following question.

	The number of electrons at each energy level		
Element	**1st Level**	**2nd Level**	**3rd Level**
Magnesium(Mg)	2	8	2
Oxygen (O)	2	6	

8 When Mg forms an ionic bond with O, how many electrons are transferred from the Mg atom to the O atom?

PS: B 9–5

A. 2
B. 6
C. 12
D. none

9 Which of the following statements describes electrons?

PS: A 9–2

A. They are positive subatomic particles located in the nucleus.
B. They are positive subatomic particles that move around the nucleus.
C. They are negative subatomic particles located in the nucleus.
D. They are negative subatomic particles that move around the nucleus.

10 Which of the following represents a pair of isotopes?

A. ^{1}H and ^{3}H
B. $^{40}K^{2-}$ and $^{40}Ca^{-}$
C. $^{16}O^{2-}$ and $^{19}F^{1-}$
D. $^{16}O^{2-}$ and $^{32}S^{2-}$

- Examine the Question
- Recall What You Know
- Apply What You Know

PS: A 9–1

11 An atom contains 12 neutrons and 11 electrons. What is the number of protons in this atom?

A. 1
B. 11
C. 12
D. 23

PS: A 9–1

12 Different isotopes of the same element have different

A. atomic numbers.
B. numbers of neutrons.
C. numbers of protons.
D. numbers of electrons.

PS: A 9–1

13 If the atom of an element has an atomic number of 15 and its atomic mass is 31, how many neutrons does it have?

A. 15
B. 16
C. 31
D. none

PS: A 9–1

14 Covalent bonds are formed when electrons are

A. transferred from one atom to another.
B. mobile within a metal.
C. captured by the nucleus.
D. shared between two or more atoms.

PS: B 9–7

15 A scientist combines hydrogen chloride (HCl) and sodium hydrochloride (NaOH) to produce table salt (NaCl) and water (H_2O). Which equation best represents what took place?

A. $2NaOH \rightarrow HCl \rightarrow 2H_2O + NaCl$
B. $NaOH + HCl \rightarrow H_2O + 2NaCl$
C. $NaOH + HCl \rightarrow H_2O + NaCl$
D. $2NaOH + 2HCl \rightarrow H_2O + NaCl$

PS: B 9–7